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European Refuse Fired Energy Systems: Evaluation of Design Practices. Volume XIV: Krefeld Co-Disposal Plant, Krefeld, West Germany

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The evaluation, which consists of two volumes of text and 15 trip reports, analyzes the experiences of the Europeans with waste to energy systems. The text is a compilation of the data obtained during visits to 15 major European refuse fired energy systems and visits to systems vendors, government agencies and other plants.

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EUROPEAN REFUSE FIRED ENERGY SYSTEMS
EVALUATION OF DESIGN PRACTICES

Krefeld Co-Disposal Plant,
Krefeld, West Germany

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Volume 14

U.S. ENVIRONMENTAL PROTECTION AGENCY
1979

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Wilhelm Körbel	Krefeld plant manager
Heinz Stögmuller	Vereinigte Kesselwerke, (VKW), Duesseldorf

PREFACE

This trip report is one of a series of 15 trip reports on European waste-to-energy systems prepared for the U.S. Environmental Protection Agency. The overall objective of this investigation is to describe and analyze European plants in such ways that the essential factors in their successful operation can be interpreted and applied in various U.S. communities. The plants visited are considered from the standpoint of environment, economics and technology.

The material in this report has been carefully reviewed by the European grate or boiler manufacturers and respective American licensees. Nevertheless, Battelle Columbus Laboratories maintains ultimate responsibility for the report content. The opinions set forth in this report are those of the Battelle staff members and are not to be considered by EPA policy.

The intent of the report is to provide decision making information. The reader is thus cautioned against believing that there is enough information to design a system. Some proprietary information has been deleted at the request of vendors. While the contents are detailed, they represent only the tip of the iceberg of knowledge necessary to develop a reliable, economical and environmentally beneficial system.

The selection of particular plants to visit was made by Battelle, the American licensees, the European grate manufacturers, and EPA. Purposely, the sampling is skewed to the "better" plants that are models of what the parties would like to develop in America. Some plants were selected because many features envolved at that plant. Others were chosen because of strong American interest in co-disposal of refuse and sewage sludge.

The four volumes plus the trip reports for the 15 European plants are available through The National Technical Information Service, Springfield, Virginia 22161. NTIS numbers for the volumes and ordering information are contained in the back of this publication. Of the 19 volumes only the Executive Summary and Inventory have been prepared for wide distribution.

ORGANIZATION

The four volumes and 15 trip reports are organized the the following fashion:

VOLUME I

A EXECUTIVE SUMMARY
B INVENTORY OF WASTE-TO-ENERGY PLANTS
C DESCRIPTION OF COMMUNITIES VISITED
D SEPARABLE WASTE STREAMS
E REFUSE COLLECTION AND TRANSFER STATIONS
F COMPOSITION OF REFUSE
G HEATING VALUE OF REFUSE
H REFUSE GENERATION AND BURNING RATES PER PERSON
I DEVELOPMENT OF VISITED SYSTEMS

VOLUME II

J TOTAL OPERATING SYSTEM RESULTS
K ENERGY UTILIZATION
L ECONOMICS AND FINANCE
M OWNERSHIP, ORGANIZATION, PERSONNEL AND TRAINING

VOLUME III

P REFUSE HANDLING
Q GRATES AND PRIMARY AIR
R ASH HANDLING AND RECOVERY
S FURNACE WALL
T SECONDARY (OVERFIRE) AIR

VOLUME IV

U BOILERS
V SUPPLEMENTARY CO-FIRING WITH OIL, WASTE OIL AND SOLVENTS
W CO-DISPOSAL OF REFUSE AND SEWAGE SLUDGE
X AIR POLLUTION CONTROL
Y START-UP AND SHUT-DOWN
Z APPENDIX

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SUMMARY

This plant is located on a broad, thinly-populated industrial area outside of Krefeld, West Germany about 30 km (20 mi) northwest of Duesseldorf. It serves a population of about 300,000.

The Krefeld plant is a part of a "sanitary park" containing the sewage treatment plant and the solid waste facility. The plant is unique in that it is the first large plant ever built to burn partially dried sewage sludge in suspension above the burning solid waste fuel bed.

Initial operation began in 1975 but because of the unique new co-firing system being applied and also because of the need to add scrubbers to remove HCl and HF from the exhaust gases, the plant has not yet been formally accepted. Accordingly, the manager was not free to release any operating data.

In the manner of mass burning of refuse, it is nearly identical to the new plant which was visited at Wuppertal. The comparative operating data, as they are developed from these two new and similar plants, will be of interest to note the effects in plant performance of sludge burning with refuse at Krefeld compared to straight refuse at Wuppertal.

Figure 5-1 shows a view of the Krefeld refuse burning plant from the adjacent wastewater plant.

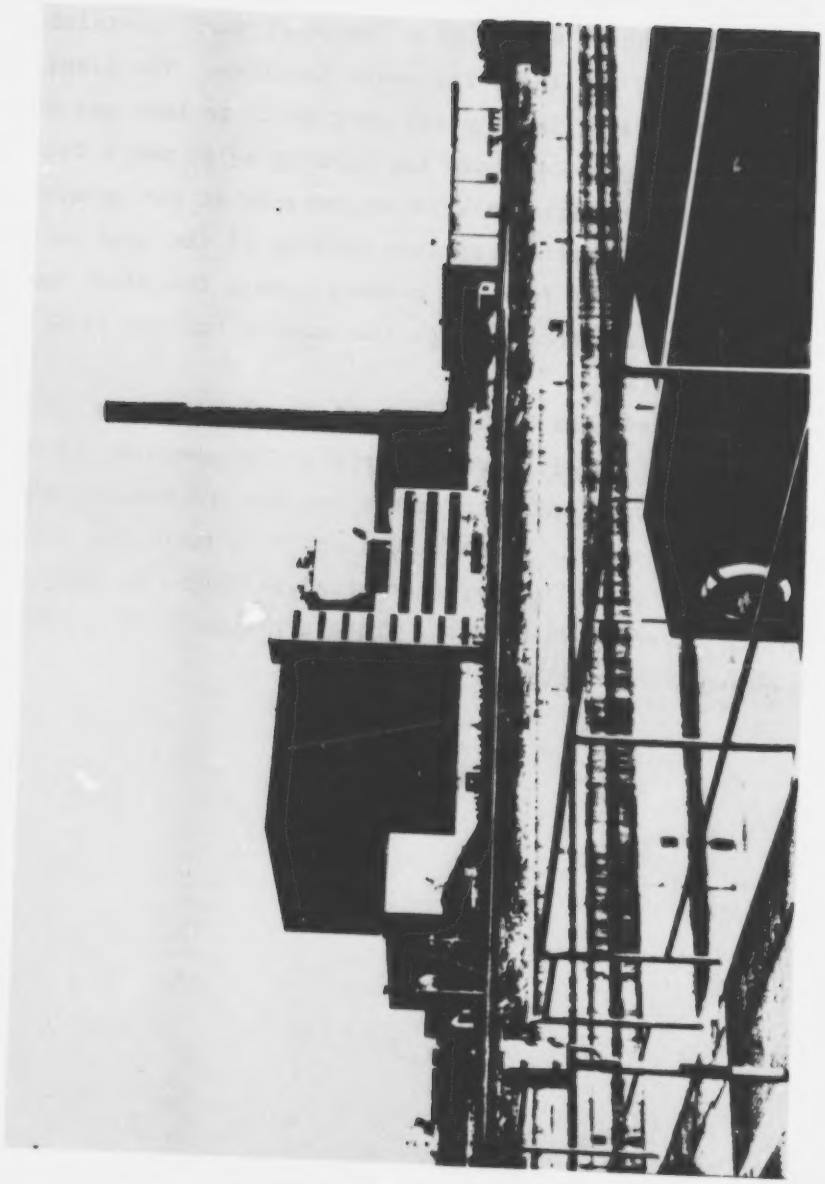

FIGURE 5-1. KREFELD PLANT EXTERIOR VIEW (Battelle Photo)

STATISTICAL SUMMARY

Krefeld Plant

Community description:	
Area (square kilometers)	_____
Population - Refuse basin (number of people)	about 300,000 or 400,000
Population - Sewage sludge basin (number of people)	about 600,000
Key terrain feature	flat - Rhine River Valley
Solid waste practices:	
Total waste generated per day (tonnes/day)	300 t/d
Waste generation rate (Kg/person/day)	_____
Lower heating value of waste (Kcal/kg)	1700 - 1800 kcal/kg
Collection period (days/week)	_____
Cost of collection (local currency/tonne)	_____
Use of transfer and/or pretreatment (yes or no)	No
Distance from generation centroid to:	
Local landfill (kilometers)	_____
Refuse fired steam generator (kilometers)	_____
Waste type input to system	mixed resid., indus.
Cofiring of sewage sludge (yes or no)	Yes
Development of the system:	
Date operation began (year)	1976
Plant architecture:	
Material of exterior construction	Aluminum, concrete
Stack height (meters)	70
Refuse fired steam generator equipment:	
Mass burning (yes or no)	Yes
Waste conditions into feed chute:	
Moisture (percent)	≈ 20%
Lower heating value (Kcal/kg)	1700 - 1800
Volume burned:	
Capacity per furnace (tonnes/hr)	12 t/h Nominal Capacity
Number of furnaces constructed (number)	2

STATISTICAL SUMMARY
(Continued)

Capacity per system (tonnes/day)	560 t/d (2 x 280 t/d)
Actual per furnace (tonnes/day)	280 t/d
Number of furnaces normally operating (number)	one
Actual per system (tonnes/day)	280 t/d
Use auxiliary reduction equipment (yes or no)	Yes, for bulky refuse
Pit capacity level full:	
(Tonnes)	2300
(m^3)	6000
Crane capacity:	
(Tonnes)	6.3
(m^3)	---
Feeder drive method	Hydraulic
Burning grate:	
Manufacturer	Vereinigte Kesselwerke
Type	Roller grate Duesseldorf
Number of sections (number)	6
Length effective	14.24 m
Width overall	3 m - Ø: 1.5 m
Primary air-max Nm^3/hr	73,800
Secondary air-overfire air-max Nm^3/hr	13,700
Furnace volume (m^3)	--
Boiler wall tube diameter (mm)	57
Furnace heating surface (m^2)	--
Auxiliary fuel capability (yes or no)	Yes (heavy fuel oil or distillate and waste oil)
Use of superheater (yes or no)	Yes
Boiler	
Manufacturer	Vereinigte Kesselwerke
Type	Natural circulation
Number of boiler passes	3
Steam production per boiler (kg/hr)	42,000
Total plant steam production (kg/hr)	84,000
Steam temperature (C)	376
Steam pressure bar	23

STATISTICAL SUMMARY
(Continued)

Use of economizer (yes or no)	Yes
Use of air preheater (yes or no)	Yes
Use of flue gas reheater (yes or no)	Yes
Cofire (fuel or waste) input	sludge
Use of electricity generator (yes or no)	Yes
Type of turbine	back pressure
Number of turbines (number)	2
Steam consumption (kg/hr)	17,500
Electrical production capacity per turbine (kw)	1400
Total electrical production capacity (kw)	2800
Turbine back pressure (bar)	3.7
User of electricity ("Internal" and/or "External")	Internal and External
Energy utilization:	
Medium of energy transfer	hot water
Temperature of medium (° C)	130/80
Population receiving energy (number)	Industrial plant making railroad cars
Pressure of medium (bar)	10
Energy return medium (~~verbal~~)	hot water (70 C)
Pollution control:	
Air:	
Furnace exit conditions	
Gas flow rate (m^3/hr)	98,600
Furnace exit loading (mg/Nm^3)	

DEVELOPMENT OF THE SYSTEM

In the 1950's it became evident that the city landfill at Fluennertzdyk, operating since 1928, was past half of its useful life and an effort was made to develop a compost system. In the dedicatory brochure[1] for the present Krefeld plant, dated March 11, 1975, Krefeld City Director Theo Fabel described the small pilot compost operation built on the theory that a natural use of the waste would be better than burning. However, meanwhile the Fluennertzdyk landfill became such a steep pile that operations on it became hazardous. Also, frequent refuse fires there caused much local annoyance from smoke and odors.

The composting effort was not deemed promising and in 1961 a Dr. Straub was engaged to study the alternatives. His report in 1964 suggested that incineration would be the best of the alternatives. Furthermore, the optimum solution suggested was to place an incineration plant adjacent to a wastewater treatment plant. However, although incineration was thought to be best, it is also the most expensive alternative. Thus, in view of the city's other needs for a bathing center, clinic, school, and new streets, there was a suggestion that rail haul be used to carry the refuse to abandoned clay pits at Lobberich. However, the geology of that place was decided to be unfavorable for proper land disposal. Accordingly, an incineration plant had to be considered, especially since the Fluennertzdykt landfill was finally estimated to be exhausted in 1975.

In 1970-71 a feasibility study of a proposed plant was made considering the combined firing of refuse and dried sludge. The study was by Projekta of Duesseldorf. On the basis of the feasibility report Projekta the prepared the specifications for the plant. Four bids were received. The evaluation of the bids was made by Kraftanlagen of Heidelberg.

There were two methods for sludge burning considered. One, proposed by Vereinigte Kesselwerke would partially dry the sludge in a centrifuge and then complete the drying in suspension in a hammer mill supplied with hot flue gases. The dried dust would then be conveyed by the hot gas flowing into the refuse-burning furnace.

The other method, proposed by Techfina would dewater it in a filter press, thermally condition the sludge, then fire it with the refuse on the grate.

On evaluation of the bids, the suspension burning system for the sludge was found to have a lower capital cost by DM 7.6×10^6 ($\$3.2 \times 10^6$). Also, the suspension burning method has already been developed for the drying and burning of high-moisture coals, hence, was judged to be ready for translation to sludge burning. In addition, mass burning of dried sludge along with refuse required about twice as long to burn sludge on a grate as does refuse. For these various reasons the VKW bid was accepted. Construction of the plant began May 18, 1973. Construction was essentially complete in late 1976 but acceptance tests were not expected at the time of our visit, May 20-23, 1977, until July, 1977.

The plant is owned by the City of Krefeld.

The plant manager is Wilhelm Körbel.

COMMUNITY DESCRIPTION

Geography

The flat surroundings of the plant shown in Figure 5-2 are typical of the terrain in the Krefeld area which is a highly industrialized community located about 30 km (20 mi) northwest of Duesseldorf. As is also evident in Figure 5-2, there is no densely populated area in the immediate vicinity of the plant--only an occasional factory.

The plant receives considerable amounts of industrial waste.

All of the energy available for export from the plant goes to one industry 2.5 km away, in the form of hot water at 130 C (266 F)/80 C (176F).

An extensive public recreation area and large, attractive shopping center are in operation and undergoing development and expansion in the immediate vicinity of the plant.

Government and Industry

Krefeld is an industrial city near the much more intensely industrialized areas of Duesseldorf and Duisburg.

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FIGURE 5-2. KREFELD WASTE PROCESSING FACILITY; WASTEWATER TREATMENT PLANT ON LEFT, REFUSE-AND SEWAGE-SLUDGE-BURNING PLANT ON RIGHT.

SOLID WASTE PRACTICES

Solid Waste Generation

Krefeld has operated a municipal landfill since 1928. The eventual exhaustion of that site led to the 1970-71 feasibility study for a waste-burning and energy-recovery utilization plant.

The average daily tonnage of refuse generated is about 280 tonnes (308 tons) per day. It is estimated that this is 75-80 percent municipal and 20-25 percent industrial. The average lower heat value is assumed to be 1700 to 1800 kcal/kg (3000 to 3200 Btu/lb). The upper design point is LHV 2500 Kcal/kg.

The new wastewater treatment plant adjacent to the refuse burning plant provides primary treatment only. Secondary treatment is to be added later in the area immediately east of the present settling basins (see Figure 5-3).

Solid Waste Transfer and/or Pretreatment

No transfer stations or pretreatment is provided except that at the bunker. There is a Lindemann shear for bulky refuse.

Solid Waste Disposal

The burned residue is not processed in any way and is trucked to a landfill and to the Netherlands for dike construction etc.

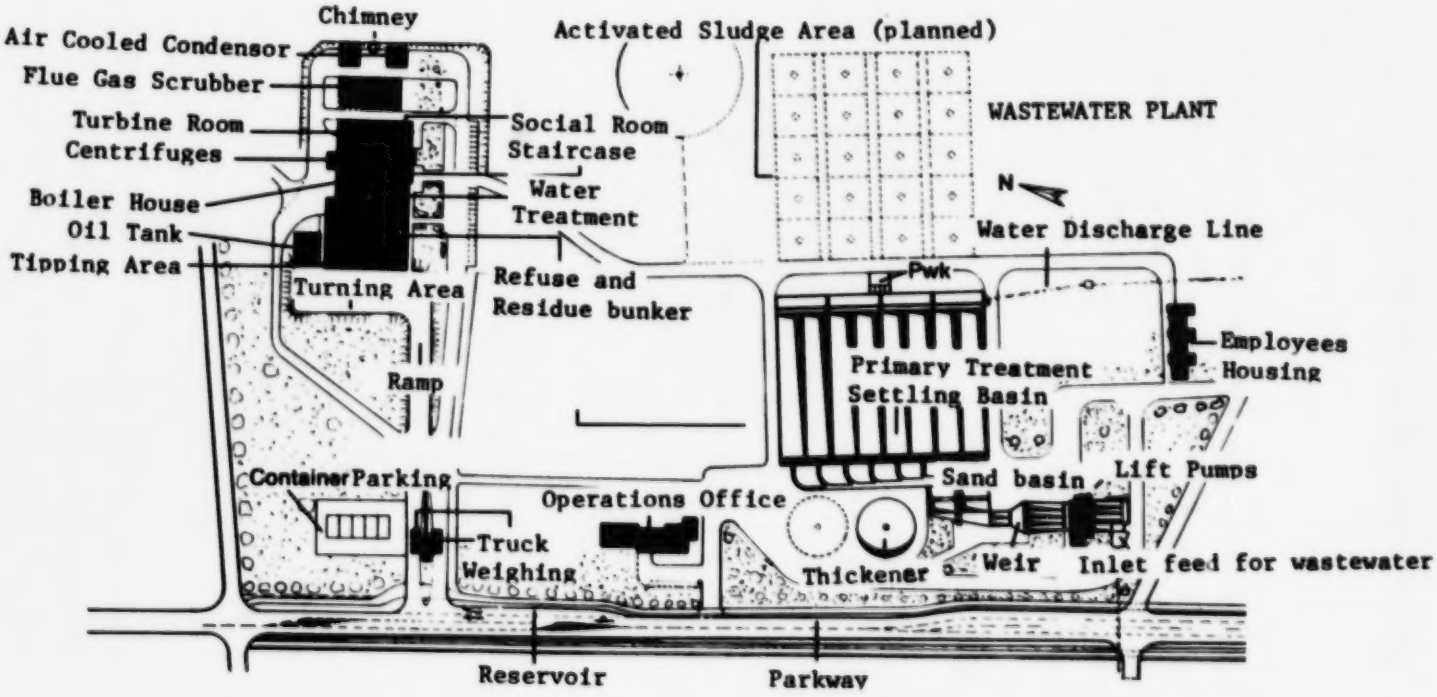


FIGURE 5-3. MAP OF THE KREFELD REFUSE BURNING AND WASTEWATER PLANTS (1)

REFUSE-FIRED STEAM GENERATOR EQUIPMENT

Waste Input

The plant receives an estimated 280 tonnes of municipal and industrial refuse per day (308 tons/day). On the basis of a 5-1/2-day week this sums up to approximately 1540 tonnes (1700 tons) per week or about 80,000 tonnes per year (88,000 tons/year). The estimated average moisture content is 20%.

Provisions to Handle Bulky Waste

Adjacent to the tipping floor is a 8 tonne (9 ton) per hour Lindemann hydraulically-driven shear. It will accept objects up to about 1.8 m (5.9 ft) and reduce them to pieces about 300 mm by 600 mm (1 ft by 2 ft). It has a shearing force of 250 tonnes (275 tons). It is operated eight hours per day by one operator. The reduced material falls directly into the pit.

Waste Storage and Retrieval

The building floor plan, Figure 5-4, shows the bunker, furnace room, and associated equipment. The bunker is 35 m long and 12 m wide (115 ft by 40 ft) and has a storage capacity of 6000 m^3 (7847 yd^3) corresponding to an average depth of 14 m (46 ft). Maximum piled capacity is about 9000 m^3 (11,772 yd^3). At a refuse density when settled and compressed of 645 lb per yd^3 (0.383 tonnes/m^3), this maximum volume represents a piled storage capacity of 3796 tons (3450 tonnes). With one unit, 12 tonnes (13.2 tons)/hr operating, this would be about 12 day's supply.

There are two cranes each of 6.3 tonnes capacity.

The holding capacity of the polygrip buckets is 4 m^3 (5 yd^3). The crane control cab is on the side of the bunker. Control is entirely manual, not semi-automatic.

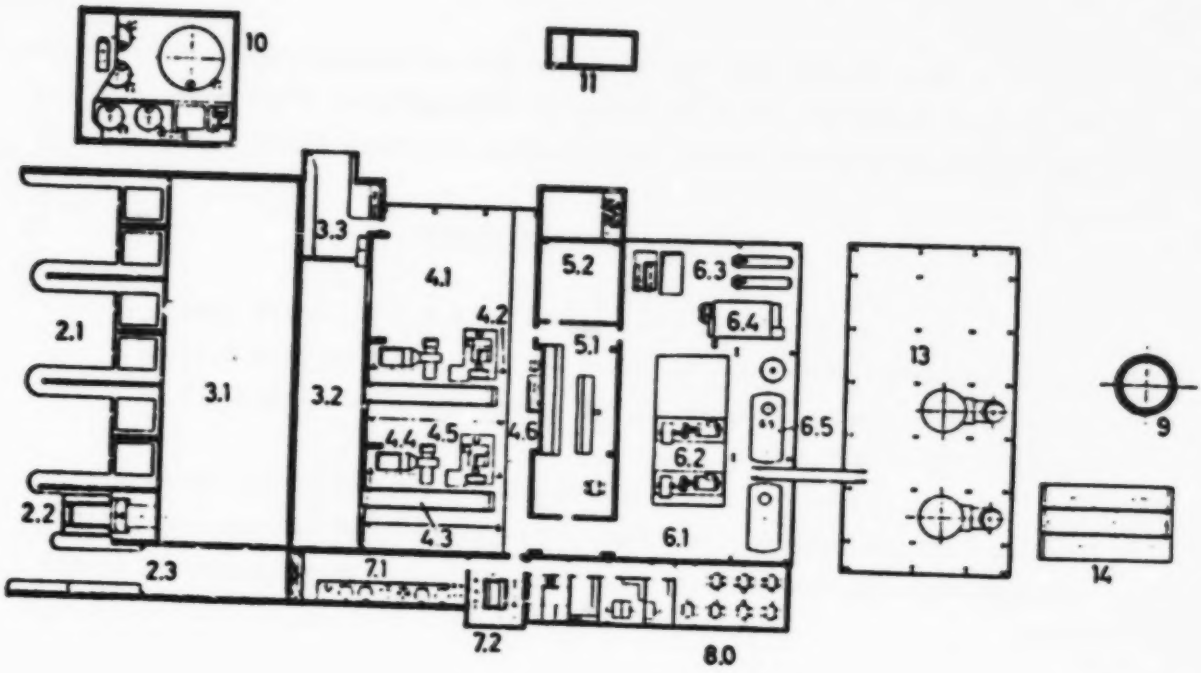


FIGURE 5-4. KREFELD WASTE-TO-ENERGY FACILITY: PLAN VIEW[2]

2.1 Tipping area
2.2 Bulky refuse shear
2.3 Auxillary tipping lane
3.1 Refuse bunker
3.2 Ash bunker
3.3 Ash loading area
4.1 Boiler house
4.2 Boiler pumps
4.3 Residue quencher
4.4 Primary air fan
4.5 Sludge-drying fan
4.6 Firing aisle
5.1 Washroom
5.2 Switch room
6.1 Turbine floor
6.2 Turbogenerator
6.3 Heat exchangers
6.4 Feedwater tank
6.5
7.1 Water treatment
7.2 Stairwell
8.0 Social room
9 Chimney
10 Waste oil facility
11 Cold water basin
13 Flue gas scrubbers
14 Condenser

Fire control for the bunker is available from a water hose and a water cannon of 150 m^3/hr capacity (660 gal/min) which uses clear effluent from the adjacent wastewater treatment plant.

Furnace Hopper and Feeder

The top opening of the hoppers is 4.5 m (14.8 ft) square. The water-cooled feed chute is 1.8 m by 2.85 m (5.9 by 19.4 ft). A hydraulically operated damper in the upper part of the chute can be closed in case of burnback.

The stroke frequency of a hydraulic ram feeder can be controlled from the main control room. The frequency of the ram can be adjusted between five and fifty strokes per hour. Normal speed is 15 per hour.

Primary Air Supply

The primary air is drawn from near the top of the refuse bunker to provide a positive inward flow of fresh air to the bunker area. Each furnace has a separate radial blower made by the Krefeld firm of Buttner-Schilde-Haas of Krefeld, a member of the Babcock group. Each can supply up to 73,800 Nm^3/hr (43,430 scfm) at 300 mm water static pressure (11.8 in). The driving motor has a power consumption of 77 kw. The supply of air to each of the six grate rollers is controlled by a manual damper and the overall supply is controlled by furnace pressure or it can be manually adjusted from the control room.

The primary air for each boiler is preheated to 50 C (122 F) by a steam heated coil made by Duerr. Its heating surface is 760 m^2 (8178 ft^2). The tubes are 35.8 I steel, 2 mm (0.080 in) thick. When heating air from 20 C to 200 C (68 F to 392 F) at the rate of 50,000 Nm^3/h (29,430 psia) at 225 C (437 F), the heat supplied is 2,816 Gcal/h (11,790 GJ/h) [11,174 Btu/h]. The corresponding steam consumption is 6500 kg/h (14,313 lb/h).

Secondary Air

One Buttner-Schilde-Haas radial blower for each furnace supplies air at a rate of 3.8 m^3/sec (13,700 Nm^3/hr) [7,980 scfm]. The available air pressure is 970 mm water static (38 in). This air is supplied to a total of 40 overfire air jets which are 70 mm (2.75 in) diameter in the front wall and 50 mm in diameter (2 in) in the upper rear wall. All of the jets are directed downward at an angle. The front wall jets are in the nose of the front wall so that their downward direction provides somewhat opposed mixing to the burning gases rising upward out of the furnace. The rear wall jets are just below the nose of the rear wall and are directed slightly downward into the initial burning zone of the furnace.

Burning Grate

Figure 5-5 shows the "walzenrost" (roller grate) which was developed beginning in 1961 at the Flingern Power Plant, in Duesseldorf, using a four-roller pilot grate applied to an old formerly coal-burning furnace. It is manufactured by the Vereinigte Kesselwerke in Duesseldorf and is generally known as the "Duesseldorf Grate". It provides a sloping fuel bed as do most European mass-burning grates for refuse. Instead of using oscillating or reciprocating grate bars to agitate the burning material and to move the incombustible residues down the slope, the walzenrost moves the bed by slow rotation of the 1.5 m (4.92 ft) diameter drums which are formed of cast iron grate sections. Thus, there is opportunity for a slow tumbling action of the refuse which helps to keep the fibrous mass loose, exposing new burning surface and allowing for a continual redistribution of the upward flow or primary air throughout the bed.

The drums rotate at an adjustable speed of about three to six revolutions per hour. Instead of being continuously exposed to the hot fuel bed, each grate bar rotates through a cool zone about half of the time.

Each grate roll is formed of ten longitudinal sections, each of which contains 60 curved grate bars. The bars at each side which rub against the air seal plates are cast of chrome-nickel alloy to resist abrasion. Out of a total of 600 bars per roll, 12 are cast alloy. There are six rolls per furnace at Krefeld.

The gap between adjacent rolls is filled by a cast iron wiper bar spaced about 10 to 15 mm from the adjacent roll. This bar is strong enough to shear off refuse that may jam in the gap or become attached to the grate.

The wiper seals are repaired three times a year. Normal wear of the seal gradually widens the gap which allows larger and larger pieces of refuse to fall through. A screw conveyor removes such residue

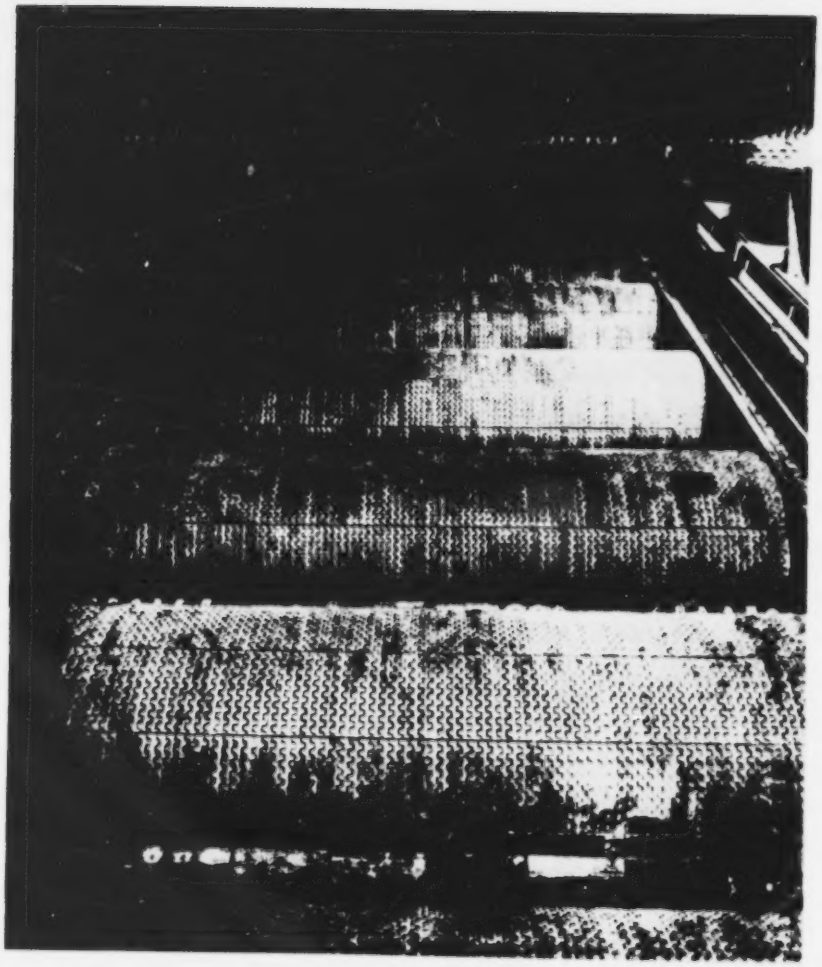


FIGURE 5-5. SIX DRUM WALZENROST (ROLLER GRATE); ALSO COMMONLY KNOWN AS THE DUESSELDORF GRATE. NOTE THE CAST IRON WIPER SEALS BETWEEN ADJACENT ROLLS WHICH PREVENT LARGE PIECES OF REFUSE FROM FALLING OUT OF THE FURNACE (Courtesy of Vereinigte Kesselwerke)

from underneath the grate but because of occasional accumulation of ash, this area is inspected once per week and cleaned every four to six months.

The roller shafts are hollow steel. Asbestos air seals at each end of the shaft require replacement every five or six years. Each roller constitutes a separate supply zone for primary air. The air enters the interior of the roll from both ends and flows through the many small gaps between the interlocking grate bars. The amount of air flow through each roll can be adjusted.

In older roller cage construction - in a part of the combusion zone (rollers 2 and 3) - melted light metals, together with siftings, through the self-cleaning effect of the grate bars, entered the grate cages and were not removed laterally in one complete revolution. This occurrence is avoided in new construction. The current roller grate design heat release rates are for grates which are essentially wider, which therefore permits higher firing rates, and these are planned for all United States projects. These firing rates are used in the refuse burning plant at Wuppertal, which has been in trouble-free operation since 1975.

No. 2 fuel is fired in two sidewall burners to attain furnace outlet temperature of 900 C (1652 F) before refuse is fired. Federal law required a startup temperature of only 800 C (1472 F). But, in this case, where partially dried sewage sludge is to be burned in suspension above the burning refuse bed, the local pollution control office requires 900 C to better assure complete combustion on startup. If the startup was only by means of refuse and sludge ignited in a cold boiler-furnace, objectionable odors would result from incomplete combustion until the system attained near normal operating temperatures.

Furnace Wall (Combustion and First Pass Radiation Chambers)

These two furnaces are partially water cooled (front and rear roof only) in accordance with the design and operating experience accumulated by VKW and its customers at the Duesseldorf plant and various other plants. The 57 mm (2.3 in) wall tubes are made of ST 35.8I carbon steel, 4 mm (0.157-inch thick). By means of welded fins, they form a continuous membrane wall. Figure 5-6 shows the plant's cross-sectional view. At the lower part of the combustion chamber, adjacent to the roller grate, pre-cast carbofrax blocks are used to protect the wall tubes.

To protect the remaining wall tubes of the combustion chamber from attack by high temperature flame impingement, they are studded and then covered with 90% silicon carbide. The welded steel studs are 10 mm diameter (0.4 in) and 20 mm (0.8 in) long. The silicon carbide coating is approximately 25 mm (1 in) thick. The studs are applied at the rate of 2100 per m^2 (195/ft^2). The studs and coating are continued upward into the radiation chamber for a distance of about 3 m (10 ft) above the refuse feed opening.

Firing of Sewage Sludge

An unusual feature of this furnace is that the dried sewage sludge is fired in suspension in hot flue gases at a point (labeled #14 in Figure 5-6) near the lower end of the radiation chamber and within the section that is coated with silicon carbide. Because the sludge particles still carry moisture (10%) and because the moisture having been vaporized out of the sludge is still in the hammermill exit gas, when both the particles and the vapor enter the hot radiation chamber they will absorb considerable heat before the particles become heated to their ignition temperature. At point #13 in Figure 5-6, a substantial amount, 2.7 to 3.9 Nm^3/sec [5715 to 8256 scfm], of hot flue gases are extracted from the furnace and sent to the sewage sludge hammermill. In the refuse and sludge burning plant at Krefeld, incoming sludge has a water content of 74 percent, and a lower heating value of about 413 Kcal/kg. It follows, therefore, that the firing of this sludge will doubtless provide additional

1. Tipping Floor
2. Refuse Bunker
3. Polyp Bucket
4. Hopper
5. Feeder
6. Roller Grates
7. Ash Bunker
8. Ash Crane
9. Boiler
10. Sludge Centrifuge
11. Sludge Hopper
12. Sludge Hammermill
13. Hot Flue Gas Takeoff for Sludge Mixing Chamber
14. Dried Sludge Entrance Port to Furnace
15. Control Room
16. Turbogenerator
17. Machine Room Crane
18. Feed Water Tank
19. Electrostatic Precipitator
20. Induced Draft Fan
21. Flue Gas Scrubber
22. Stack

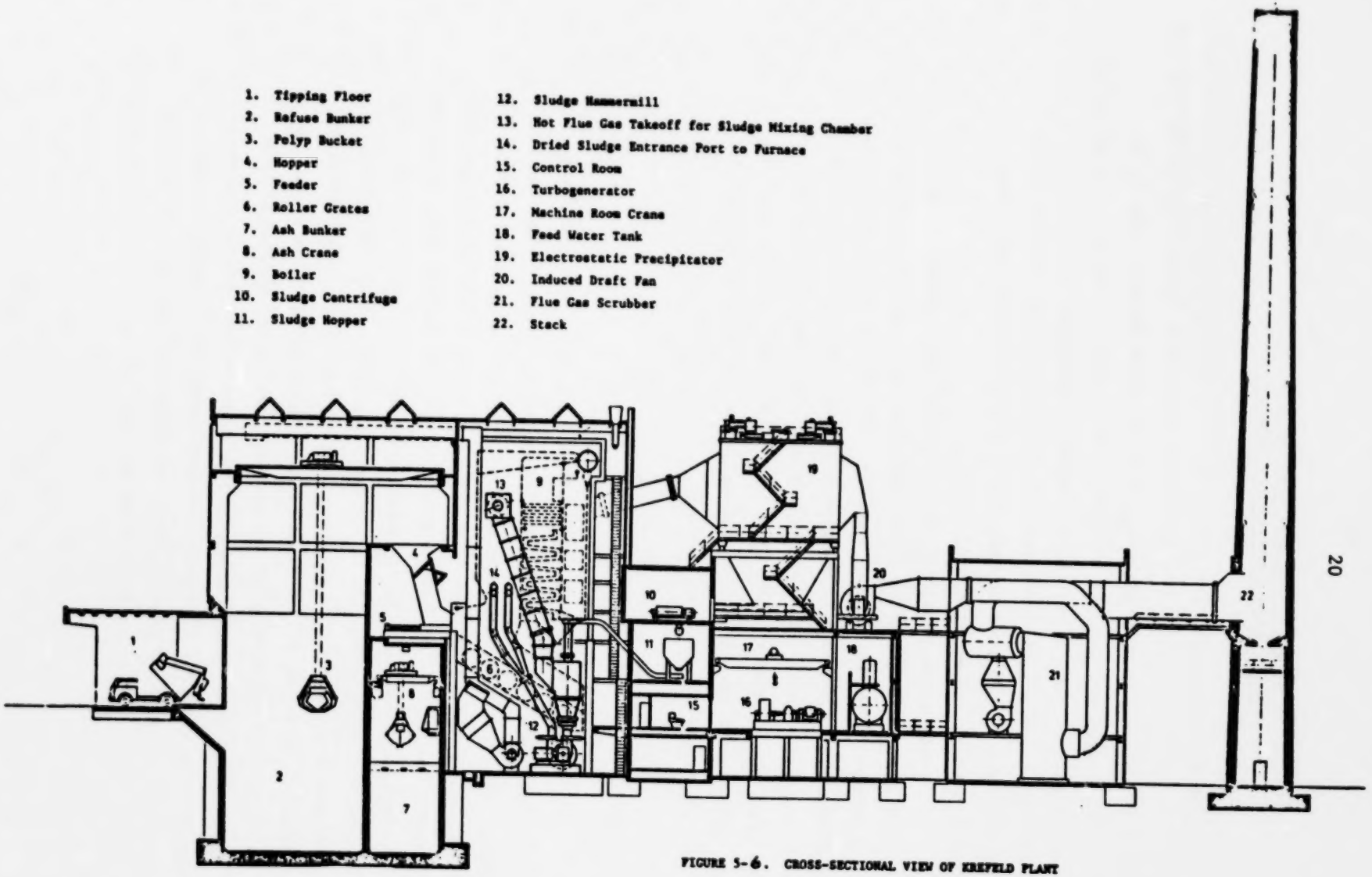


FIGURE 5-6. CROSS-SECTIONAL VIEW OF KREFELD PLANT

(Courtesy City of Krefeld)

steam production capacity. Support from an amount of supplementary heat is required when an unexpected reduction of the lower heating value occurs. A negative effect of sludge burning on power production, therefore, does not occur. To the contrary, there is a resulting increase in energy production. The operating methods of a refuse-fired boiler plant with co-disposal of sludge do not produce problems with superheater temperature control. Customary procedures for boiler cleaning are, of course, necessary.

Second Boiler Pass - Superheater and Convection Section

The superheater consists of 50 tubes, 51 mm (2.0 in) diameter with a wall thickness of 3.6 mm (0.14 in) and formed of 35.8 I steel. The composition of 35.8 I steel is as follows:

$C \leq 0.17\%$	$P \leq 0.050$
$Si \leq 0.18$	$S \leq 0.050$
$Mn \geq 0.50$	$Cr \leq 0.030$

In West Germany this steel is identified under Standard No. 1.0305.

The gas temperature entering the superheater is estimated to be 700 to 750 C (1292 to 1382 F). There is one steam soot blower. The steam flow rate is 42 tonnes/hr (46 tons/hr) at 23 bars (333 psia) and 376 C (709 F).

The boiler convection section consists of six banks of sloping tubes, also made of 35.8 I steel, 57 mm (2.2 in) in diameter, 3.6 mm (0.14 in) thick. The boiler water walls are 57 mm in diameter and 4 mm thick.

Economizer

The economizer is 1.9 by 3.6 by 7 m (6.2 by 12 by 23 ft) and as shown in Figure 5-6, is contained in the third boiler pass. The tubes are made of 35.8 I steel, 38 mm (1.5 in) diameter and 3.2 mm (0.13 in) thick. The boiler water walls are 57 mm in diameter and 4 mm thick.

Boiler Water Treatment

Water treatment is provided by the usual deionizing and deoxidizing system.

Heating Surface

The approximate heating surface in the various boiler components are as follows:

	m^2	ft^2
Water-tube walls*		
Boiler	1190	12,803
Superheater	252	2,711
Economizer	457	4,919
Total	1899	20,430

The tubular cooler for moderating the superheated steam temperature has a surface of 22 m^2 (237 ft^2).

* Includes walls of combustion chamber, radiation first pass, second pass, and third pass.

Heat Release Rate

The following heat release rates have been estimated from dimensions scaled from Figure 5-6. The effective grate area is 42.63 m^2 (458.9 ft^2), corresponding to a grate width of 3.0 m (9.8 ft). The total furnace volume up to the throat where the gases enter the radiation chamber is 79 m^3 (2790 ft^3). For the purpose of estimating volume heat release rate, half of the height of the radiation chamber up to the beginning of the turn of the gases toward the superheater has been assumed to serve as combustion volume; that is, one half of 136 m^3 (4803 ft^3) or 68 m^3 (2401 ft^3) is added to the estimated furnace volume of 79 m^3 (2790 ft^3) for a total assumed, active combustion volume of 147 m^3 (5191 ft^3).

Table 5-1 shows the resulting estimated dimenstions and rates. The grate burning and heat release rates are moderate.

TABLE 5-1 . ESTIMATED BURNING VOLUME DIMENSIONS AND HEAT RELEASE RATES FOR EACH OF THE TWO KREFELD FURNACES (LHV Assumed 2250 Kcal/kg) (4050 Btu/lb)

	m	ft
Grate area effective	42.63 m^2	458,9 ft^2
Furnace volume	79.0 m^3	2790 ft^3
Radiation chamber volume	136.0 m^3	4803 ft^3
Furnace plus 1/2 rad. ch. vol.	147.0 m^3	5191 ft^3

	Design Rate
Total daily firing rate	288 tonnes/day
" hourly " "	12 tonnes/hr
Firing rate per boiler	13.2 tons/hr
Heat input per boiler	27.0 Gcal/hr
" " " "	113.0 GJ/hr
" " " "	106.9 MBtu/hr
Grate burning rate	281.5 kg/m^2-hr
" " "	51.6 lb/ft^2-hr
Grate heat release rate	633,375 $kcal/m^2$-hr
" " " "	2652 MJ/m^2-hr
" " " "	233,487 Btu/ft^2-hr
Volume heat release rate	183,673 $kcal/m^3$-hr
" " " "	769 MJ/m^3-hr
" " " "	67,709 Btu/ft^3-hr

Energy Utilization Equipment

In addition to the utilization of thermal energy for drying of sewage sludge, some of the energy released in the burning of refuse and dried sludge is sent as hot water at 130 C (266 F) 10 bar (145 psia) to a railroad car plant located 2.5 km (1.5 mi) away. The water return temperature is 70 C (158 F) at 7 bar (100 psia). Steam is used to drive two turbo generators, built by AEC, having a generation capacity of 1.4 mw each at 10 kv. Each turbine can utilize 17.5 tonnes/h (38,500 lb/h). The design steam outlet conditions are 3.7 bar (53.7 psia) and 206 C (403 F).

The excess steam is used for preheating the primary combustion air to 200 C (392 F). Each of two heaters, made by Duerr, uses 6500 kg/h (14,300 lb/h) saturated steam at 25 bar (363 psia) 225 C (437 F). The heating capacity is 2.816 Gcal/h (11.79 MJ/h) [11,175 Btu/h] when heating air at the rate of 50,000 Nm^3/h (29,425 scfm).

More steam is used internally for one Lugar flue gas reheater following the scrubbers. Using 3,150 kg/h (6930 lb/h) of steam at 22 bar (320 psia) and 375 C (707 F), the heater is designed to heat the saturated flue gas from about 60 C (140 F) to 90 C (194 F).

Most of the electricity generated is used internally. Any excess goes to the local network without payment.

Energy is sold to the local railroad car plant and is used internally for primary air heating, sludge drying, electric motors, flue gas reheating.

Sludge Treatment and Burning

As indicated in the dotted area in Figure 5-3, immediately east of the present settling tanks, an activated sludge treatment addition is planned. This however will have no significant effect on the amount of energy required for sludge driving, because the additional activated sludge treatment section and the third refuse fired boiler will be built both at some time in 1980-81. For the utilization of the increased thermal energy after one more boiler will be set into operation (i.e. 1 boiler= standby) a 13 Megawatt turbine set is planned.

Figure 5-7 shows the sludge handling system. The settled sludge is not pumped without further treatment to the dewatering plant and an added chemical conditioner. Then, with a water content of about 94 percent, it is pumped to the centrifuge which reduces the water content to about 74 percent and a lower heating value of 413 kcal/kg (1800 kJ/kg) (752 Btu/pound). The removed water is returned to the wastewater treatment plant.

The partially dewatered sludge then flows to a surge tank and thence to the large Babcock mills, one per boiler, where it is mechanically disintegrated by the high speed paddles in an atmosphere of air mixed with hot flue gas which is taken from near the top of the boiler radiation pass as shown in Figure 5-6 . It thus enters the lower part of the boiler radiation chamber conveyed in an atmosphere of vapor and partially cooled flue gas. Experience has shown that if this saturated conveying stream is allowed to cool too much, some of the vapor will be recondensed on the very large surface available on the fine sludge particles. It is estimated that the moisture content of the sludge particles entering the radiation pass is about five to ten percent and its net lower heat value is about 2,500 kcal/kg (10,467 kJ/kg) [4,500 Btu/lb]. Long experience with mill drying of brown coal has indicated that the moisture content should not be allowed to become too low as this greatly increases fire and explosion hazard within the mill system.

Figure 5-8 shows the estimated conditions entering and leaving the drying mill as a function of drying rate. At full design rate the furnace burns 12 tonnes/hr (13.2 tons/hr) of refuse plus 6.43 tonnes/hr (7.1 tons/hr) of dewatered sludge. If, because of a reduced heat value

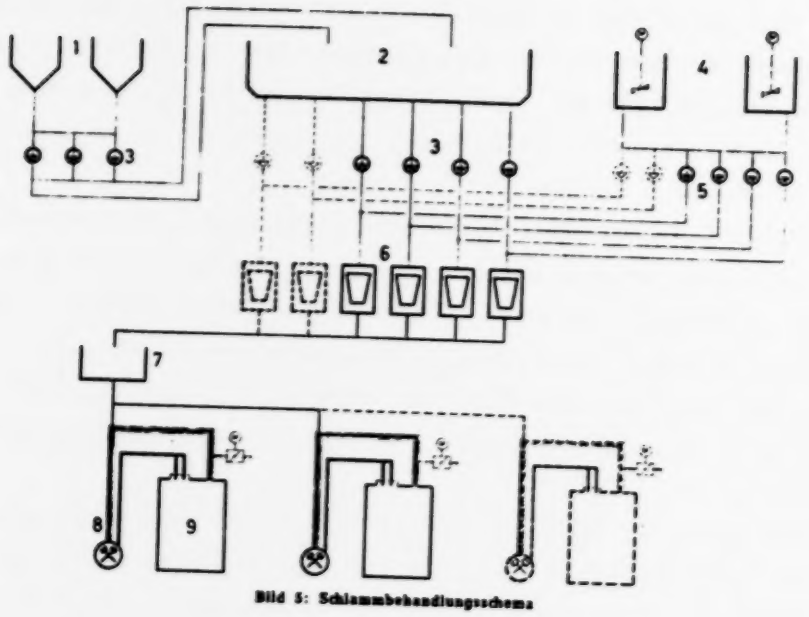


Bild 5: Schlammbehandlungsschema

FIGURE 5-7. KREFELD SLUDGE-PROCESSING AND BURNING SYSTEMS (COURTESY VEREINIGTE KESSELWERKE).

1. Thickener
2. Sludge Tank
3. Sludge pump
4. Flocculating tanks
5. Metering pumps
6. Centrifuges
7. Surge tank
8. Heated hammer mill
9. Boiler

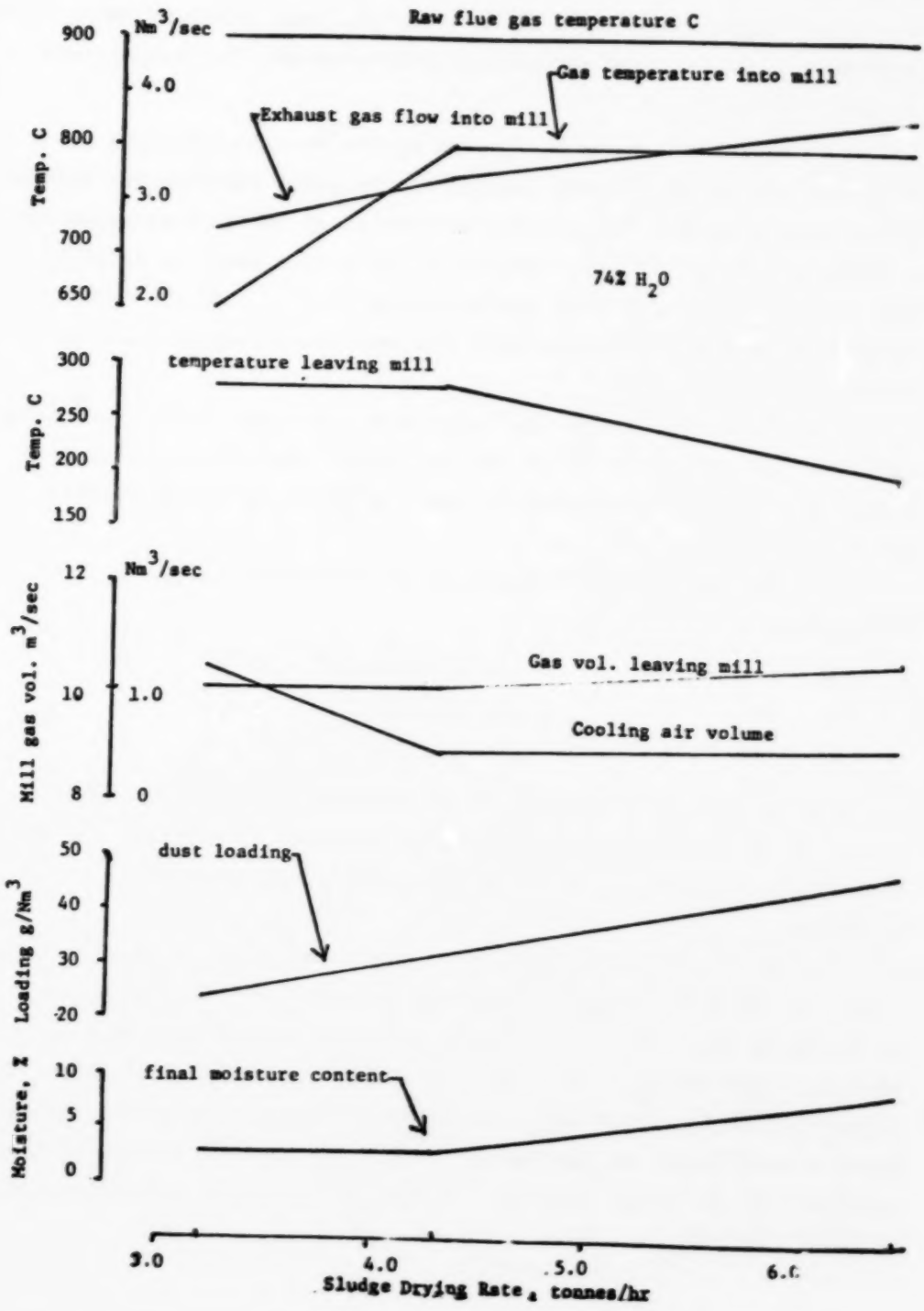


FIGURE 5-8. CALCULATED DRYING MILL CONDITIONS AS A FUNCTION OF SLUDGE DRYING RATE (Courtesy of Vereintgte Kessel-werke)

in the refuse or because of an extra moisture load in the sludge, the first pass outlet temperature falls below the legal limit of 800 C (1472 F), supplemental oil is fired automatically to maintain that temperature. (TA-Luft regulations).

Table 5-2 shows the drying system design conditions as affecting the estimated dust loading of the gases entering the electrostatic precipitator. Three different levels of refuse heat value are considered. Note that the "effective" grate area shown is 42.63 m^2 (458.9ft^2) as contrasted with the estimated 35.7 m^2 (383 ft^2) used in the section on heat release where only the equivalent flat surface is considered.

Figure 5-9 shows the calculated dust load of the flue gases for various "flow rates" of ash across the grate. The three calculation points on the curve correspond to the conditions in Columns marked 1, 2, and 3 in Table 5-2 .

The approximate composition of the sludge coming to the centrifuges at Krefeld is:

Dry solids	6.5 to 7.0%
Ash	2.8 to 3.2%
Ash/solids	40.0 to 45%

If the sludge is held too long in the thickener, digestion causes a loss of volatiles which affects its burning characteristics. Mr. Koerbel emphasized that a key element in successful sludge processing is to keep it moving.

At present the quantity of sludge available is greater in relation to the refuse quantity that would normally be encountered. It is estimated that the sludge to the Krefeld plant comes from an area serving a population of about 600,000 while the 400 tons of refuse per day is from a population of about 300,000. Some local plants such as Bayer process their own wastewater. When the Krefeld wastewater plant is modified for secondary treatment existing regulations covering pre-treatment of industrial wastes will be enforced.

TABLE 5-2. SLUDGE DRYING MILL DESIGN CONDITIONS FOR WASTE OF THREE LOWER HEATING VALUES[1]
(Courtesy Vereinigte Kesselwerke)

Refuse Lower Heating Value	Kcal/Kg	2,500	1,600	1,000
CO_2 Before Electrostatic Precipitator	%	11.5	11.5	11.5
CO_2 Max	%	19.5	19.5	19.5
Flue Gas Temperature	°C	250	212	192
Flue Gas Volume from Refuse [3]	Nm^3/h	64,100 n = 1.7	45,200 n = 1.7	31,900 n = 1.7
Flue Gas Volume from Sludge	Nm^3/h	12,300 n = 1.0	12,300 n = 1.0	12,300 n = 1.0
Flue Gas Volume from Oil	Nm^3/h	--	5,200 n = 1.02	15,100 n = 1.02
Total Flue Gas Volume	Nm^3/h	76,400	62,700	59,800
Flue Gas Volume per Second	m^3/s	40.65	30.94	28.06
Flue Gas Density	Kg/Nm^3	1.265	1.23	1.195
Flue Gas Pressure Before Filter	mmWs	60	52	46
Ash in Waste	%	16.5	24	29
Ash in Waste	Kg/h	1,980	2,880	3,480
Ash in Sludge	Kg/h	690	690	690
Total Ash	Kg/h	2,670	3,570	4,170
Grate Surface Area	m^2	42.63	42.63	42.63
Raw Flue Gas Dust Loading Corrected to 10% CO_2	mg/Nm^3	4,200 to 8,600	6,400 to 12,800	8,600 to 17,400
Raw Flue Gas Dust Loading Corrected to 11.5% CO_2	mg/Nm^3	4,820 to 9,900	7,360 to 14,720	9,900 to 20,000
Cleaned Flue Gas Dust Loading Corrected to 7% CO_2	mg/Nm^3	100	100	100

(1) A common input tonnage is assumed to be

Refuse	12.00 tonne/hr
Sludge	6.43
Waste Oil	1.26
Total	19.69 tonne/hr

(2) Calculated for a barometer reading (760 mm Hg) [29.92 in Hg]

(3) n = assumed excess air ratio

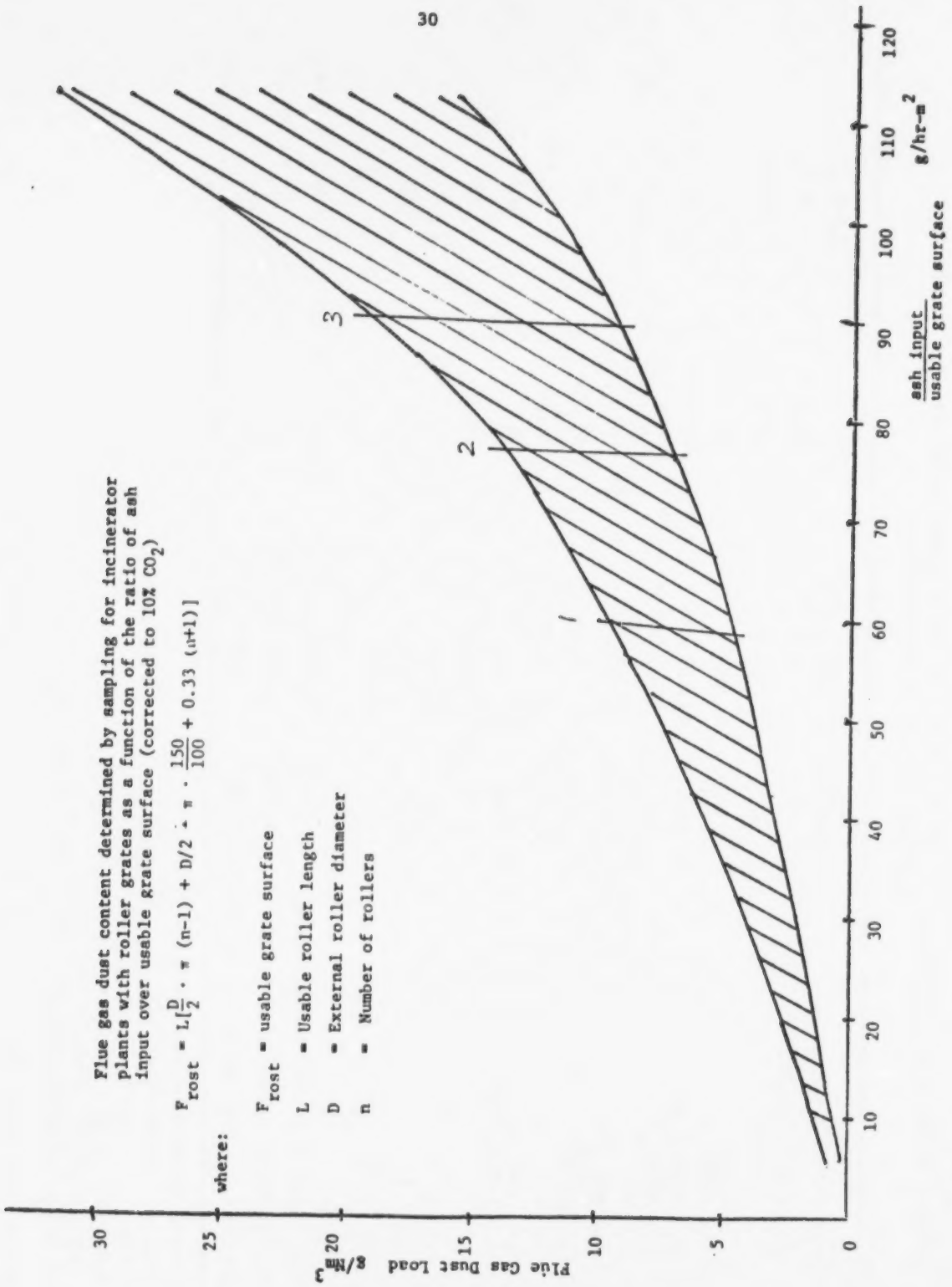

Flue gas dust content determined by sampling for incinerator plants with roller grates as a function of the ratio of ash input over usable grate surface (corrected to 10% CO_2)
$F_{rost} = L[\frac{D}{2} \cdot \pi \cdot (n-1) + D/2 \cdot \pi \cdot \frac{150}{100} + 0.33\ (n+1)]$
where:
F_{rost} = usable grate surface
L = Usable roller length
D = External roller diameter
n = Number of rollers
Flue Gas Dust Load g/Nm³
ash input / usable grate surface g/hr-m²
1
2
3

FIGURE 5-9. CALCULATED DUST LOAD OF THE FLUE GAS AS A FUNCTION OF THE AMOUNT OF ASH ON THE GRATE (Courtesy Vereinigte Kesselwerke)

The sludge drying system was not operating during either day of our visit, May 20, 23, 1977, and data could not be released on the drying system performance because acceptance tests had not yet been run on the plant. However, a published design heat balance is said to be available from a recent article in VGB Kraftswerkstechnik.

Although the plant is equipped to handle waste oil, the facilities are not in use. Apparently, waste oil in this area all goes to waste oil refiners.

Near the completion of this EPA project, after Battelle project funds had expired, we developed more photographs and Grumman provided us with a technical paper written in German. We have translated the labels and the figures are attached in the appendix in the hopes of providing yet more useful information on co-disposal at Krefeld. Limitation on funds, unfortunately, prevents us from integrating these photos and figures into the text.

Wastewater Discharge

The principal wastewater is from the sludge centrifuges. The wastewater is returned to the adjacent wastewater treatment plant.

POLLUTION CONTROL EQUIPMENT

Electrostatic Precipitators

The exhaust gases are cleaned by two electrostatic precipitators and will be cleaned also by two scrubbers when they become operational.

Previously, in Table 5-2 the estimated dust loading entering the precipitator was tabulated. Table 5-3 gives the design characteristics of the precipitators. No test data are yet available on precipitator performance. The precipitator was built by Buttner-Schilde-Haas of Krefeld, a member of the Babcock group, under license from Svenska Flaktfabriken.

While visiting this plant, May 20, 23, 1977, the stack plume from single boiler operation was usually invisible. At one period, during startup with the heavy oil burner, some smoke was observed.

TABLE 5-3 . CHARACTERISTICS OF THE TWO KREFELD PRECIPITATORS

Gas quantity	88,000 Nm^3/h
Gas temperature	300° C
Raw gas dust load at 11.7 % CO_2	20 g/Nm^3
Cleaned gas dust load at 7% CO_2	100 mg/Nm^3
Number of electrical fields	2
Number of rapped fields	2
Active length	7.2 m
Active width	6.5 m
Active height	7.5 m
Gas passages	26
Active volume	351 m^3
Collector plate projected area	2810 m^2
Collector plate effective area	3800 m^2
Gas velocity	1.025 m/s
Cross sectional area	48.75 m^2
Residence time	7.02 s
Drift velocity	3.29 s
Number of power supplies	2
Electrical characteristics	45 kV eff.
Sparking voltage	64 kV_s
Secondary current	600 mA_m
Sparking current	1020 mA eff.
Power input per field	46 kVa
Power consumption	27.6 kW
Power to rappers	4 x 0.055 kW
Insulation heaters	8 x 2.0 kW
Current density	0.426 mA/m^2
Sparking current density	3.42 mA/m^3

Source: Courtesy Vereinigte Kesselwerke.

Scrubbers

In 1974 a new Federal regulation of atmospheric emissions was enacted known as TA Luft (Technischen Anleitung zur Reinhaltung der Luft). It reduced the allowable particulate emission for plants over 100,000 m^3/h (58,850 cfm) to 100 mg/Nm^3 corrected to eleven percent O_2. For new plants it also specified limits for emission of HCl, HF, CO, NO_2, and SO_2. For plants which expand by adding new capacity, all of the old and new equipment must meet following new limits on gases:

HCl: 100 mg/Nm^3 (67 ppm) [0.083 lb/1000 lb gas]

HF: 5 mg/Nm^3 (24 ppm) [0.008 lb/1000 lb gas]

Accordingly, a scrubber system has been added to this plant following the precipitator and also following the induced draft fan. A simple outline of the Lugar scrubber and flue gas reheat system is shown in a separate building to the right in Figure 5-6. The scrubbers (assuming they follow a properly designed ESP) are designed to achieve the following emissions:

HCl: 100 mg/Nm^3

SO_2: 100 mg/Nm^3

HF : 5 mg/Nm^3

NO_x: 265 mg/Nm^3

Figure 5-10 shows the water systems for the entire plant including the scrubber. The sketch of the scrubbers implies that the scrubbers are simple vertical spray-type units with some provision for demisting. Previously, the diagram in Figure 5-6 showed a separate fan and steam-heated air heater for mixing hot air with the cool, saturated gases leaving each scrubber. The design characteristics of that flue gas reheat system were described under Energy Utilization.

No test data are yet available on the flue gas cleaning system. Assuming that the scrubber system can be brought to a high level of reliable operation, this plant will then become one of the most advanced waste-to-energy plants in the world.

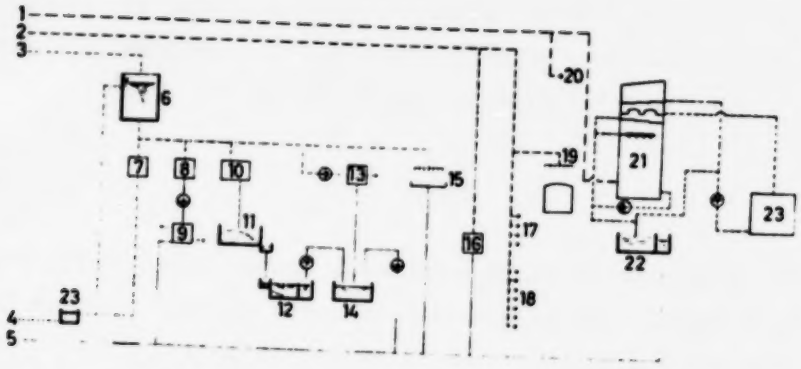


FIGURE 5-10. SUPPLY AND WASTEWATER SYSTEMS

1. Clear water from wastewater treatment plant
2. City water
3. Well water
4. Percolation well
5. Wastewater canal
6. Well water reservoir
7. Cold water discharge
8. Flocculating tank
9. Sludge centrifuge
10. Quench tank
11. Ash bunker
12. Settling tank
13. Boiler feedwater treatment
14. Neutralizing tank
15. Washroom
16. Sanitary wastes
17. Exterior hydrants
18. Tipping floor hydrants
19. Fire control cannon-bunker
20. Oil tank
21. Flue gas scrubber
22. Neutralization tank
23. Lime mixing tank

Stack Construction

The 70 meter (230 ft) stack is shown in cross section in Figure 5-6 . The lining is acid-resistant brick. External diameter is 3.65 m (12 ft), internal diameter is 2.75 m (9 ft).

Noise

The plant has no close neighbors, hence, noise is not a current problem. Furthermore, the machinery components are all enclosed within the structures and the ambient area is unusually quiet.

PERSONNEL AND MANAGEMENT

The plant operates 24 hours per day, three shifts, seven days per week. The individual work week is 40 hours.

ECONOMICS

Capital Investment

The plant cost DM 58.5 x 10^6 (23.8 x 10^6 lat DM 2.46/$).

Operating Costs

Because of the newness of the plant and its operations no data are yet available on operating costs.

Revenues

The only income to the Krefeld plant comes from the sale of the energy in hot water to a local railroad car plant at the rate of DM 30-35/Gcal (DM 7-8/GJ) [$3.6 - $4.2/MBtu]. The design rate for energy export was 14 Gcal/hr (55,552 MBtu/hr).

REFERENCES

1. Plant dedication brochure: "Müll-und Klärschlaum-Verbrennungsanlage und Klarwerk Krefeld", dated March 11, 1975.

2. B. W. Westphal and J. Böhme, "Müll-und Klarschlamnverbrennungs-anlage Krefeld" Energie, Vol. 5, 1975.

3. Article in VGB Kraftswerkstechnic describing design heat balances.

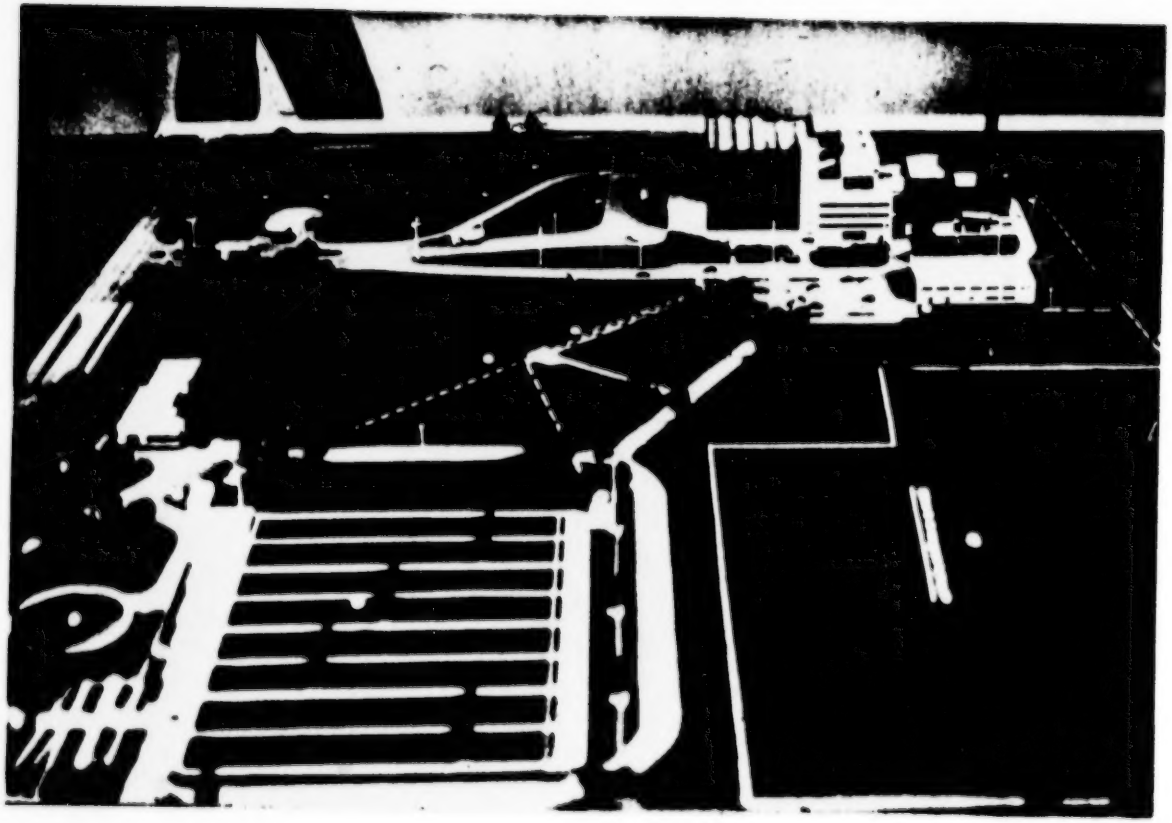


FIGURE 5-A. PHOTO OF MODEL SHOWING THE ENTIRE ENERGY AND ENVIRONMENTAL PARK AT KREFELD

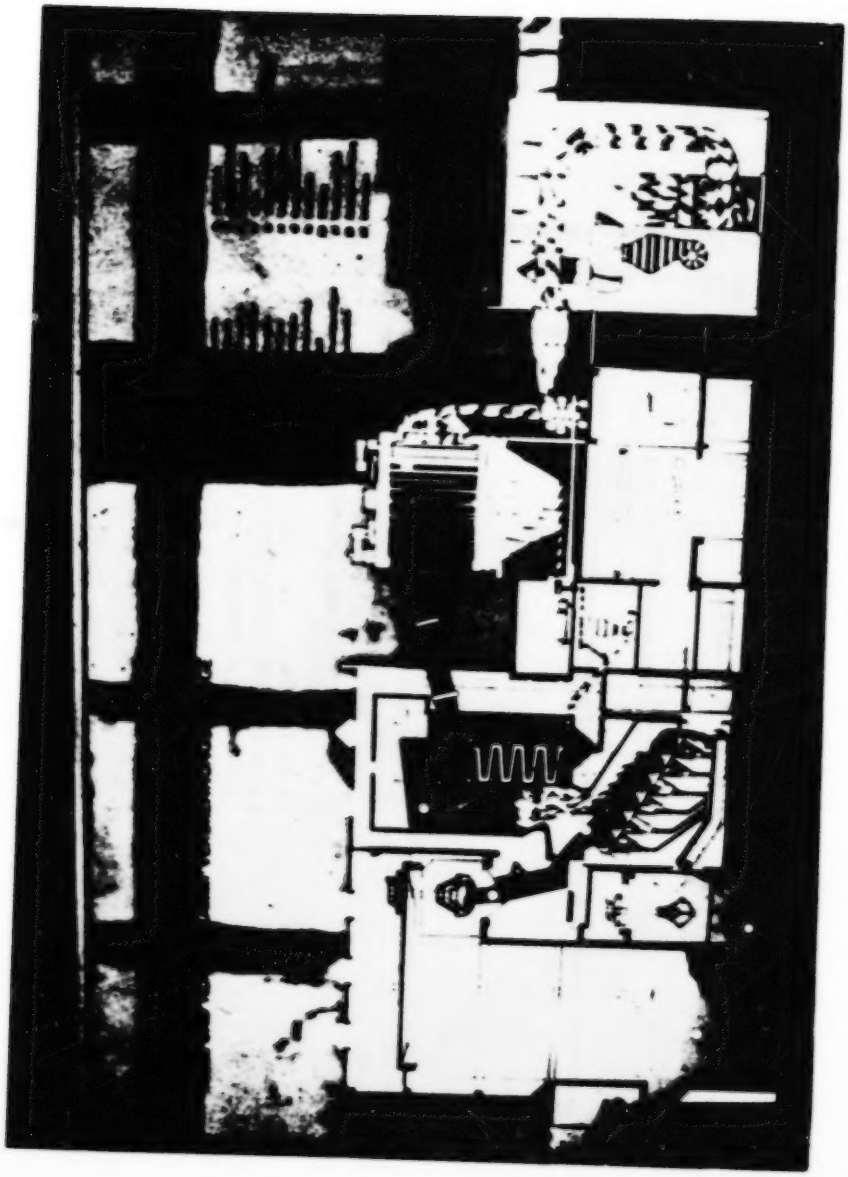
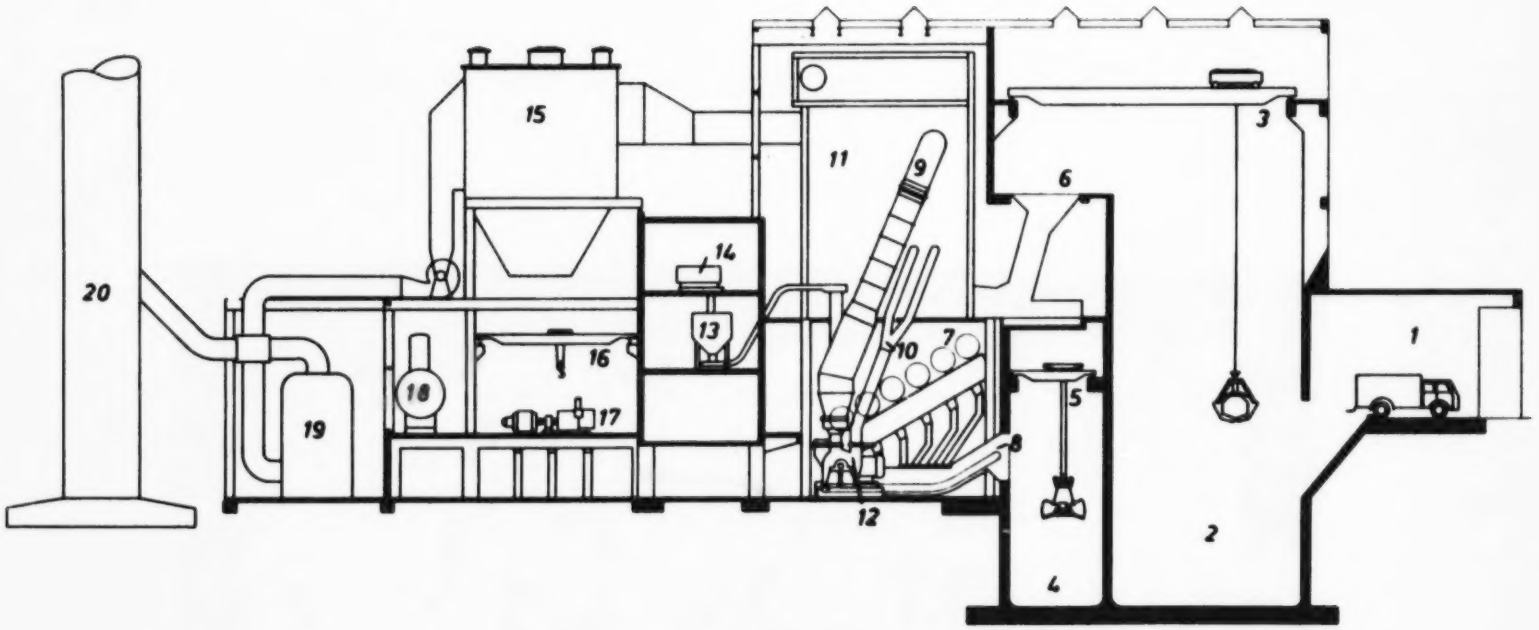


FIGURE 5-B. PHOTO OF KREFELD MODEL SHOWING FLOW OF FLUE GAS



1 = Tipping Floor
2 = Refuse Bunker
3 = Polyp Bucket
4 = Ash Bunker
5 = Ash Crane
6 = Hopper
7 = Duesseldorf Roller Grates
8 = Ash Conveyor
9 = Hot Flue Gas Takeoff Going to sludge mixing chamber
10 = Dried Sludge pneumatic Duct to furnace
11 = Boiler
12 = Sludge Drier
13 = Sludge Bunker
14 = Centrifuge
15 = Electrostatic Precipitator
16 = Room Crane Turbogenerator
17 = Turbogenerator
18 = Feed Water Tank
19 = Flue Gas Washer*
20 = Chimney Stack

FIGURE 5-C. SIMPLIFIED KREFELD SCHEMATIC (DOES NOT SHOW THE BOILER DETAIL OF FIGURE 5-6, PAGE 20) (DOES SHOW ASH REMOVAL DETAIL)

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* Actually a two stage scrubler

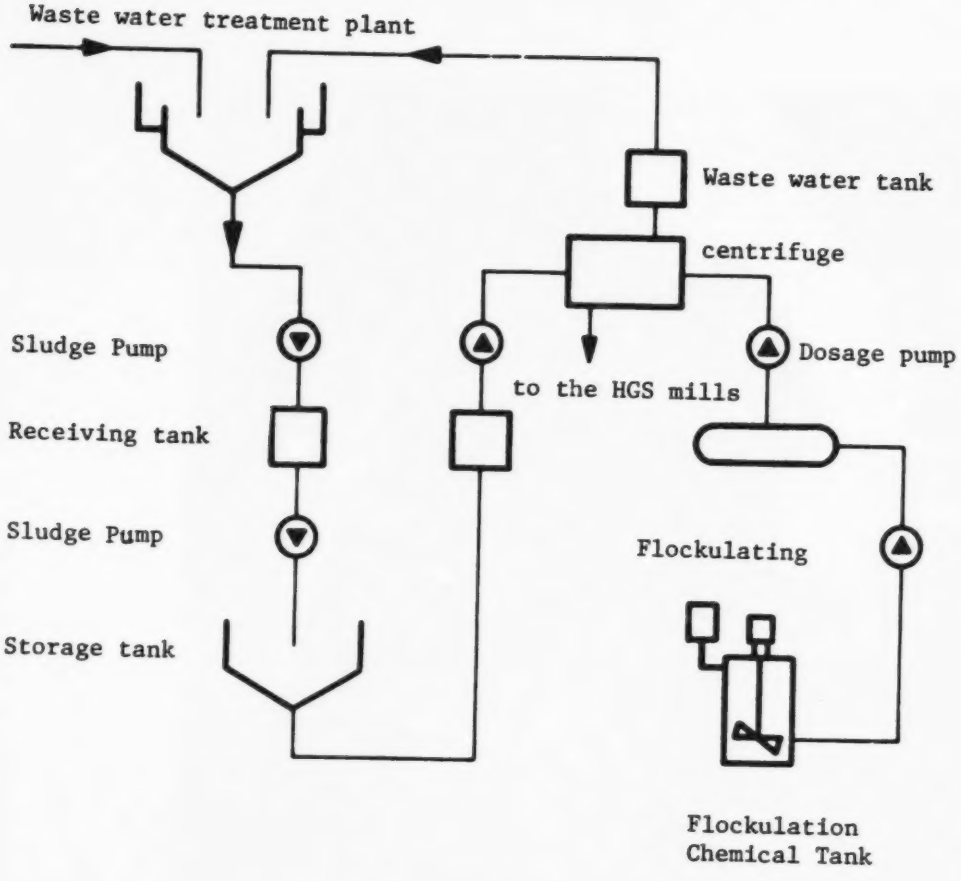


FIGURE 5-D. WET SLUDGE PREPARATION AND CENTRIFUGE

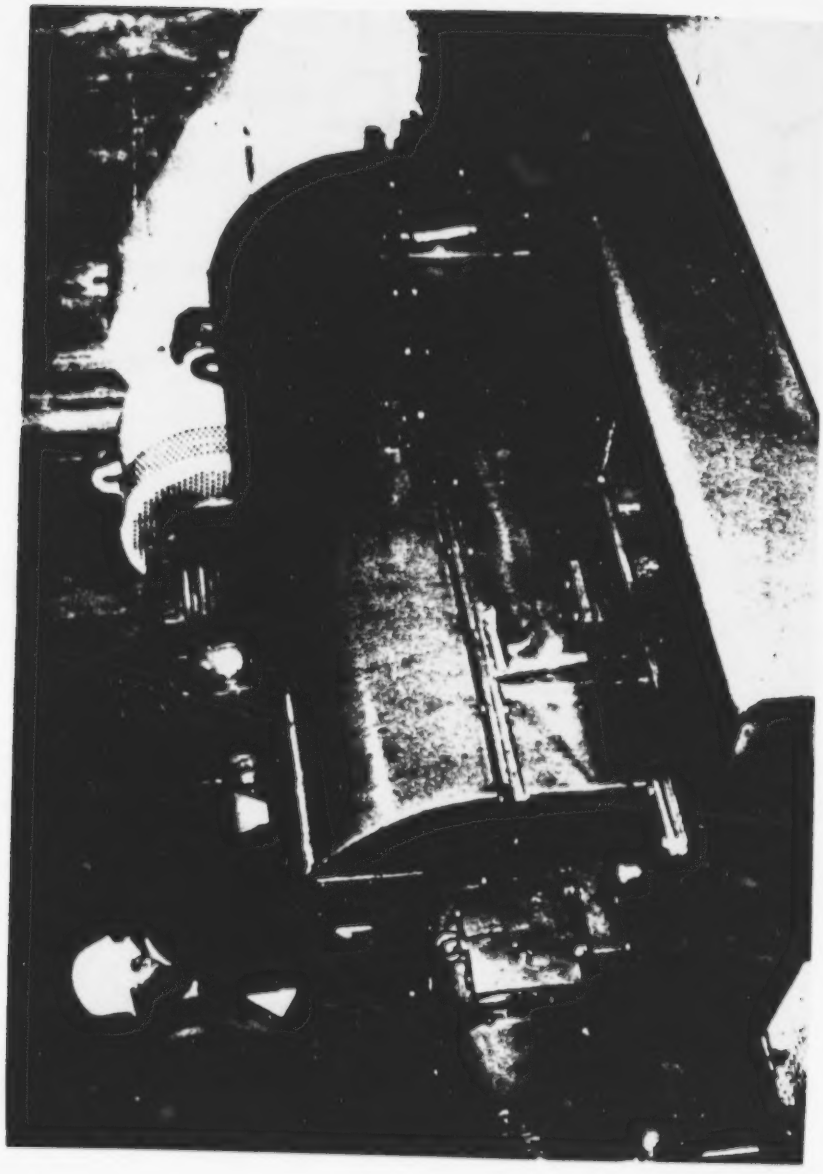
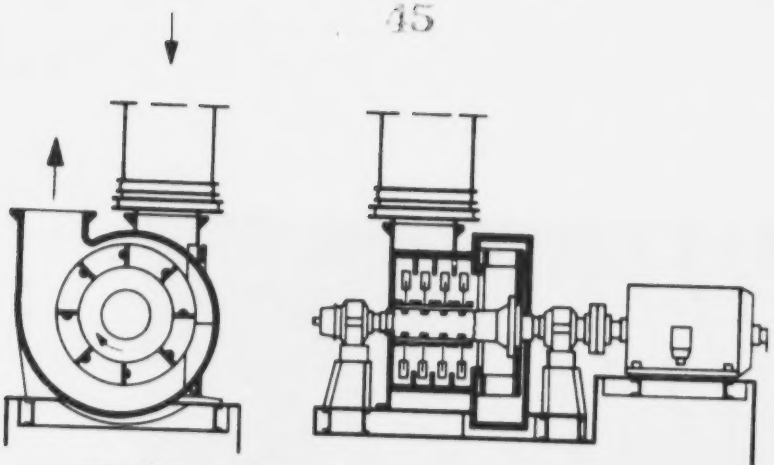


FIGURE 5-E. CENTRIFUGES AT KREFELD USED TO REDUCE MOISTURE CONTENT OF SEWAGE SLUDGE FROM 96% DOWN TO 74%



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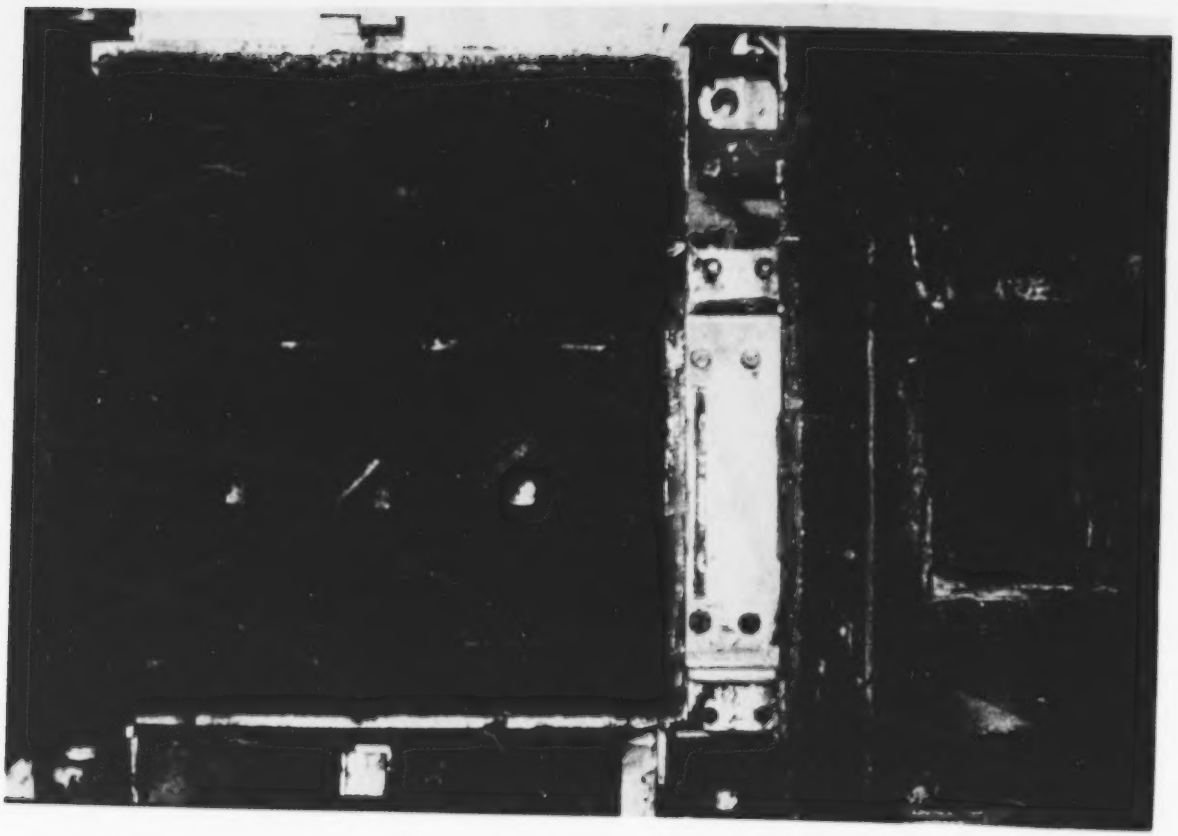


FIGURE 5-F. HGS HORIZONTAL AXIS
PADDLE WHEEL
SLUDGE DRIER

FIGURE 5-G. WATER TUBE WALLS - FIN TUBE WELDED IN GROUPS OF 8
AT UKW PLANT IN DUESSELDORF DESTINED FOR SINGAPORE

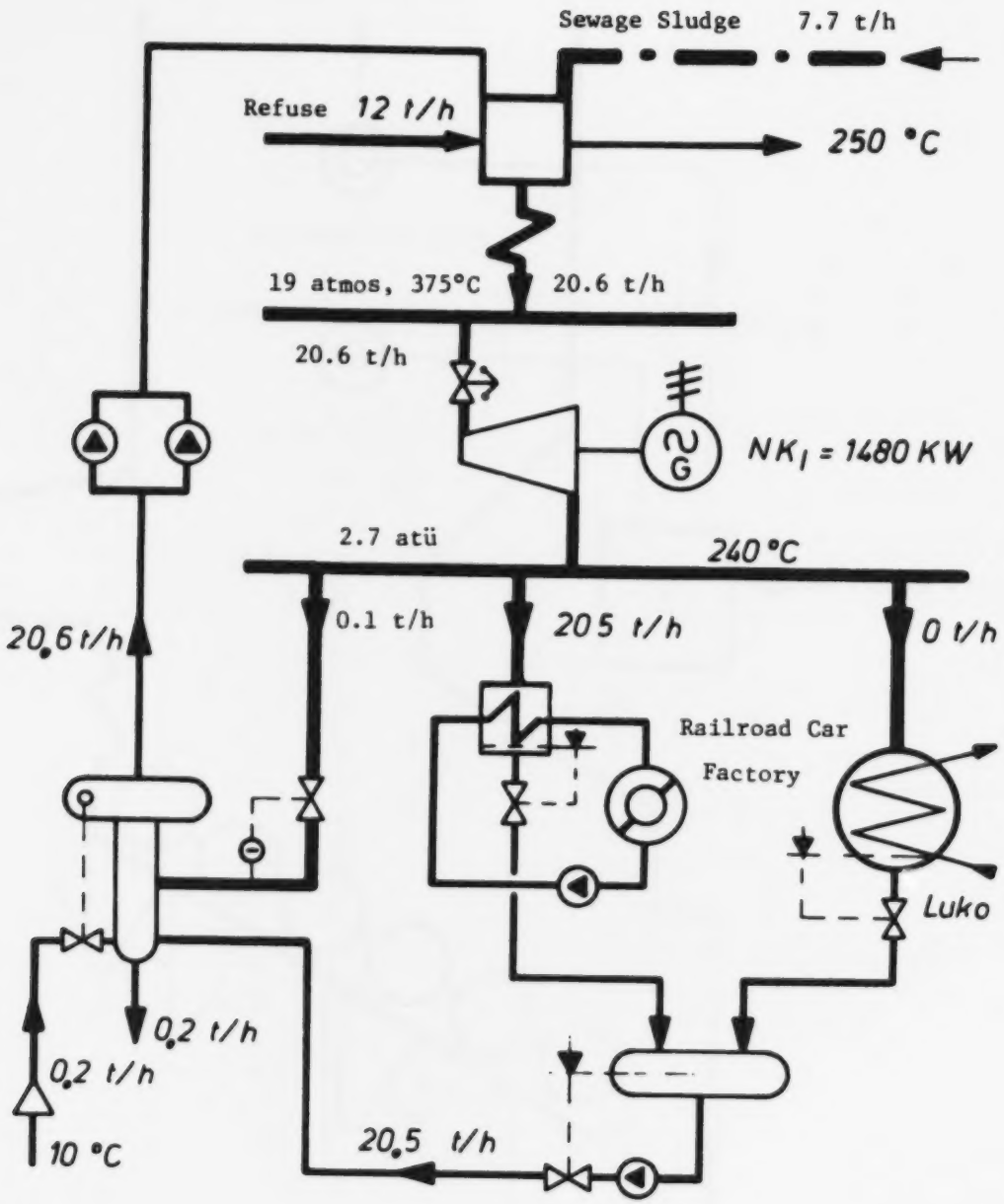
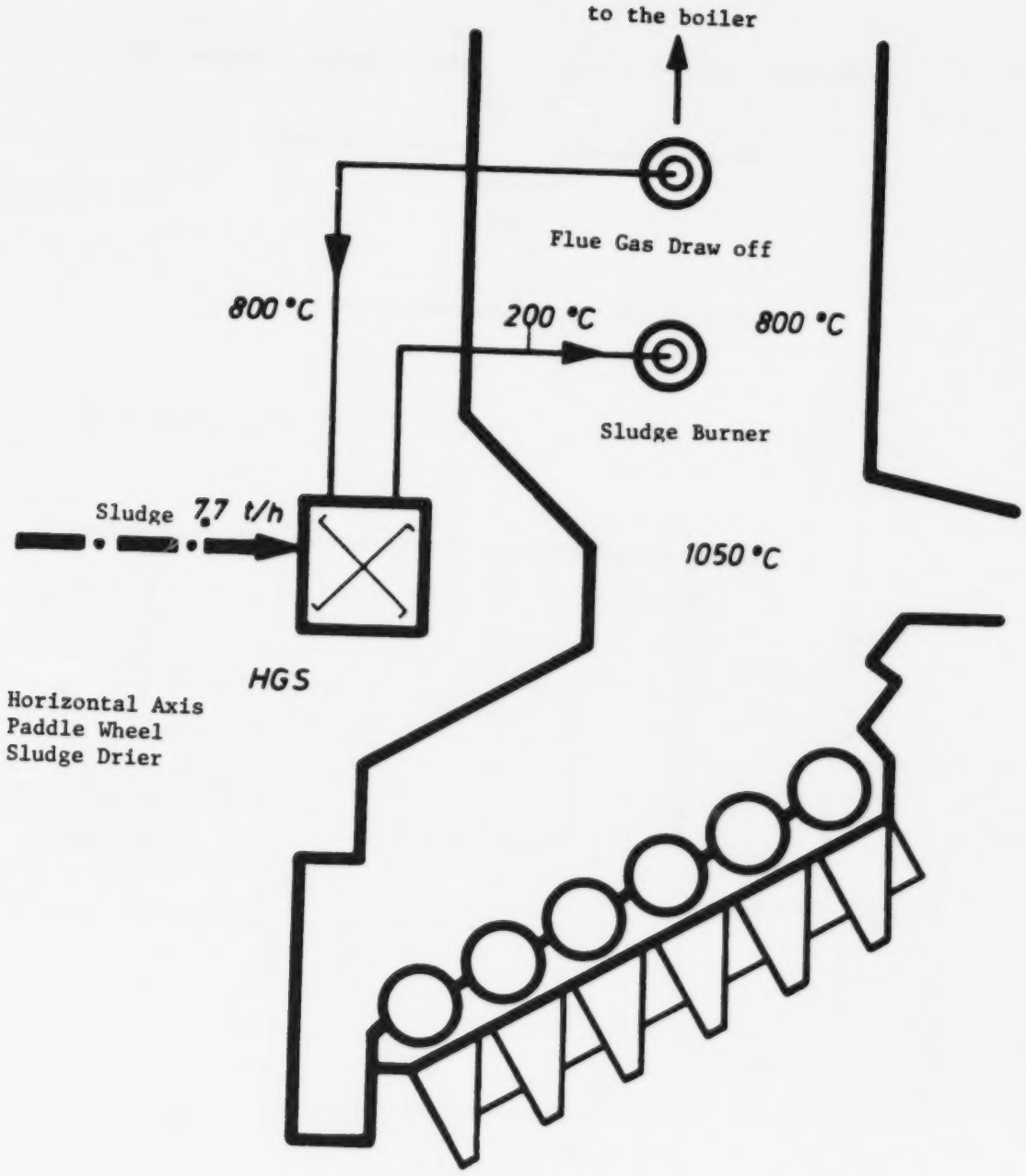


FIGURE 5-H. HEAT FLOW DIAGRAM



Grate Firing of Refuse: 12 t/h, H_u = 1600 kcal/kg, n = 1.6.

HGS-Sludge Drier: 7.7 t/h Sludge, W = 74%, H_u = 284 kcal/kg

FIGURE 5-J. FLUE GAS DRAW OFF AND SLUDGE FIRING AT KREFELD

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by
feet	meters	0.3048
square feet	square meters	0.0929
cubic feet	cubic meters	0.0283
inches	millimeters	25.4
cubic yards	cubic meters	0.7646
barrels (oil)	cubic meters	0.15899
miles	kilometers	1.609
square miles	square kilometers	2.589
acres	square kilometers	0.004047
acres	hectares	0.4047
gallons	cubic meters	0.003785
ton (short)	tonne (metric)	0.9078
pounds	grams	454
grains	grams	0.0648

To Convert From	To Get	Multiply by
meters	feet	3.281
square meters	square feet	10.76
cubic meters	cubic feet	35.31
millimeters	inches	0.0394
cubic meters	cubic yards	1.308
cubic meters	barrels (oil)	6.290
kilometers	miles	0.6214
square kilometers	square miles	0.3861
square kilometers	acres	247.1
hectares	acres	2.471
cubic meters	gallons	264.2
tonne (metric)	ton (short)	1.102
grams	pounds	0.002046
grams	grains	15.42

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CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by
pounds per million Btu	nanograms per Joule	499.2
pounds per million Btu	milligrams per megajoule	499.2
cubic feet per minute	cubic meters per hour	1.699
gallons per minute	liters per minute	3.785
pounds per square foot	kilograms per square meter	703.1
pounds per square inch	kilograms per square centimeter	0.07031
pounds per square inch	atmospheres	0.0681
pounds per square inch	newtons per square meter	6894.8
pounds per square inch	kilopascals	6.8948
atmospheres	bars	1.0133
atmospheres	kilopascals	101.3
pounds per square inch	bars	0.06895
inches of water	pascals	249.08
millimeters of water	pascals	9.806

To Convert From	To Get	Multiply by
nanograms per Joule	pounds per million Btu	0.0023
milligrams per megajoule	pounds per million Btu	0.00233
cubic meters per hour	cubic feet per minute	0.588
liters per minute	gallons per minute	0.264
kilograms per square meter	pounds per square foot	0.001422
kilograms per square centimeter	pounds per square inch	14.223
atmospheres	pounds per square inch	14.69
newtons per square meter	pounds per square inch	0.00014
kilopascals	pounds per square inch	0.1450
bars	atmospheres	0.9869
kilopascals	atmospheres	0.0098
bars	pounds per square inch	14.50
pascals	inches of water	0.004015
pascals	millimeters of water	0.102

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CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
Btu	kilocalorie	0.252	kilocalorie	Btu	3.968
MBtu	Gcal	0.252	Gcal	MBtu	3.968
Btu	kilowatt-hours	0.000293	kilowatt-hours	Btu	3414
Btu	Joules	1055.1	Joules	Btu	0.000948
Btu per pound	kilocalories per kilogram	0.5555	kilocalories per kilogram	Btu per pound	1.8
Btu per pound	Joules per kilogram	2326	Joules per kilogram	Btu per pound	0.00430
Btu per hour	watts	0.29307	watts	Btu per hour	3.413
Btu per sq ft-hr	kilocalories per sq meter-hr	2.711	kilocalories per sq meter-hr	Btu per sq ft-hr	0.3688
Btu per cu ft-hr	kilocalories per cu meter-hr	8.897	kilocalories per cu meter-hr	Btu per cu ft-hr	0.112
pounds per 1000 pounds(gas)	grams per cu meter	1.205	grams per cu meter (gas)	pounds per 1000 pounds	0.93
grains per cu ft (68 F)	grams per cu meter (20 C)	2.28	grams per cu meter (20 C)	grains per cu ft (68 F)	0.43

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TABLE EXCHANGE RATES FOR SIX EUROPEAN COUNTRIES, (NATIONAL MONETARY UNIT PER U.S. DOLLAR) 1948 TO FEBRUARY, 1978(a)

	Denmark Kroner (D.Kr.)	France Francs (F.Fr.)	W. Germany Deutsch Mark (D.M.)	Netherlands Guilders (Gl.)	Sweden Kronor (S.Kr.)	Switzerland Francs (S.Fr.)
1948	4.810	2.662	3.333	2.653	3.600	4.315
1949	6.920	3.490	4.200	3.800	5.180	4.300
1950	6.920	3.499	4.200	3.800	5.180	4.289
1951	6.920	3.500	4.200	3.800	5.180	4.369
1952	6.920	3.500	4.200	3.800	5.180	4.285
1953	6.920	3.500	4.200	3.786	5.180	4.288
1954	6.914	3.500	4.200	3.794	5.180	4.285
1955	6.914	3.500	4.215	3.829	5.180	4.285
1956	6.914	3.500	4.199	3.830	5.180	4.285
1957	6.914	4.199	4.201	3.791	5.173	4.285
1958	6.906	4.906	4.178	3.775	5.173	4.308
1959	6.908	4.909	4.170	3.770	5.181	4.323
1960	6.906	4.903	4.171	3.770	5.180	4.305
1961	6.886	4.900	3.996	3.600	5.185	4.316
1962	6.902	4.900	3.998	3.600	5.186	4.319
1963	6.911	4.902	3.975	3.600	5.200	4.315
1964	6.921	4.900	3.977	3.592	5.148	4.315
1965	6.891	4.902	4.006	3.611	5.180	4.318
1966	6.916	4.952	3.977	3.614	4.180	4.327
1967	7.462	4.908	3.999	3.596	5.165	4.325
1968	7.501	4.948	4.000	3.606	5.180	4.302
1969	7.492	5.558	3.690	3.624	5.170	4.318
1970	7.489	5.520	3.648	3.597	5.170	4.316
1971	7.062	5.224	3.268	3.254	4.858	3.915
1972	6.843	5.125	3.202	3.226	4.743	3.774
1973	6.290	4.708	2.703	2.824	4.588	3.244
1974	5.650	4.444	2.410	2.507	4.081	2.540
1975	6.178	4.486	2.622	2.689	4.386	2.620
1976	5.788	4.970	2.363	2.457	4.127	2.451
1977	5.778	4.705	2.105	2.280	4.670	2.010
1978 (Feb.)	5.580	4.766	2.036	2.176	4.615	1.987

(a) Exchange Rate at end of period.

Line "ae" Market Rate/Par or Central Rate.

Source: International Financial Statistics: 1972 Supplement; April, 1978, Volume XXXI, No. 4, Published by the International Monetary Fund.

* U. S. GOVERNMENT PRINTING OFFICE : 1979—620-007/6307